TIMED Lights Out Operations

David LaVallee
Senior Professional Staff
Johns Hopkins University
Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723
Phone: 240.228.4546
Fax: 240.228.1093
David.LaVallee@jhuapl.edu

William Knopf
TIMED Mission Operations Manager
Johns Hopkins University
Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723
Phone: 240.228.6416
Fax: 240.228.3202
Bill.Knopf@jhuapl.edu

Abstract— The current budget environment of low cost spacecraft and operations support drives the need for innovative methods for maximizing science return while reducing the risk to the missions. The solution includes increased automation of routine activities, anomaly detection, data gathering and problem notification.

NASA's Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) spacecraft is a low-earth orbiter studying the influences of the sun and humans on the least explored and understood regio[1]n of Earth's atmosphere. The Johns Hopkins University Applied Physics Laboratory (JHU/APL) built and is operating the TIMED spacecraft for NASA.

Mission Operations developed techniques for automating the contact activities, monitoring and evaluating the downloaded data and paging operators when problems are discovered. During each contact, two expert systems monitor the housekeeping telemetry for anomalous conditions and SSR dump status. Page messages are sent for critical conditions, giving mission operations immediate information on the spacecraft status. The automated system increases capacity, efficiency and timeliness of the operation.

The system allows autonomous execution of passes. Currently approximately 50% of the contacts are staffed and 50% are unstafffed. These additional contacts deliver more timely notification of anomalous situations as well as more timely science data. To support all of these contacts without an automated system, at least 13 fulltime mission operators would be required instead of the current staffing level of 7.

[1] 0-7803-7651-X/03/$17.00/© 2003 IEEE
[2] IEEEAC paper #1202, December 10, 2002

TABLE OF CONTENTS

1. INTRODUCTION

The Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics (TIMED) Mission is the first in NASA's Solar Connections Program. Launched on December 7, 2001, this highly sophisticated small spacecraft contains four remote sensing instruments onboard. It is studying the influences of the sun and humans on the least explored and least understood region of Earth's atmosphere – the Mesosphere and Lower Thermosphere/Ionosphere. TIMED is operated by a small Mission Operations Team at The Johns Hopkins University Applied Physics Laboratory (JHU/APL). The 625km orbit, inclined at 74.1 degrees, enables multiple daily contacts with the Satellite Control Facility, collocated with Mission Operations at JHU/APL.

The current budget environment of low cost spacecraft and operations support drives the need for innovative methods for maximizing science return while reducing the risk to the missions. As spacecraft become more complex, the effectiveness of operators visually checking telemetry for anomalies is decreased. [1] TIMED has over 30,000 telemetry points in its telemetry dictionary. The solution includes increased automation of routine activities, anomaly detection, data gathering and problem notification. Earlier notification of problems leads to a more timely solution and reduces the loss of science data caused by an idle spacecraft.

The TIMED Mission Operations Team consists of seven people: an Operations Manager, and six others who conduct all aspects of planning, control, and assessment. Since the team is so small, it is highly beneficial to augment it with automated processes that allow the team to be proactive and efficient in conducting operations. By maintaining a healthy spacecraft state, efficient coordination with the instrument teams, and keeping up with retrieval of the high data volume recorded daily on the spacecraft's solid state recorders, Mission Operations works to ensure mission success. Efficient operations and the ability to quickly respond to spacecraft or ground anomalies minimize the risk of spacecraft and instrument degradation and maximize return of science data. As of the writing of this paper, the TIMED Mission Operations Team has realized a 100% return of science data recorded on the spacecraft. A strong contributing factor to this success rate is a level of automation that permits unattended, or "lights out", operations during hours of the day that are not routinely staffed. TIMED has been utilizing its lights out capability on a daily basis since January 2002.

2. OBJECTIVE

The initial TIMED Concept of Operations included analyzing housekeeping telemetry to verify nominal operation using an automated process. It also included the use of a semi-automated process to receive daily data recorder dumps and to upload spacecraft commands. However, the baseline plan only supported passes when the Mission Operations Center (MOC) is staffed during a single shift, seven days per week. There was a desire, but not a requirement, for an automated system that would increase capacity, efficiency and timeliness. [2]

The objectives of lights out automation for TIMED are twofold. First, the automation is intended to "conduct" contacts with the spacecraft when operations personnel are not available. Due to the nature of TIMED's orbit, passes over the APL Satellite Control Facility occur one or two times per cluster, with two clusters per day separated by approximately 12 hours. Contact times range from 5 to 11 minutes in duration. Precession of TIMED's orbit causes these passes to change by approximately 19 minutes per day. Mission Operations is staffed 10 hours a day, 7 days a week, and typically only one cluster is actively supported while the other is run "lights out". The lights out contacts provide the ability to downlink spacecraft housekeeping and science data, while monitoring for routine health and safety indications.

The second objective of lights out operations is to notify the appropriate people of a problem. It is important to get a Mission Operations "human in the loop" quickly in the event of an anomalous condition. The lights out processes should be able to do this based on autonomous assessment of pre-specified data. Autonomous lights out tools should provide the operations personnel with additional information to allow an informed decision process to proceed. The most basic anomalous indication would be that the lights out contact did not work as planned. These tools can also help, for example, to anticipate if additional contacts need to be scheduled, what state will the spacecraft be in for the next contact, is the spacecraft power positive, is science data in danger of being overwritten on the recorder, etc. Returning the spacecraft to normal operating mode as quickly as possible will increase the science data return. The early detection of problems and the availability of supporting information from automated processes can provide a high level of protection of spacecraft assets and more rapid recovery from faults, all while reducing operations costs through utilizing such a small Operations Team.

3. APPROACH

Our approach to achieving lights out operations involves using proven general-purpose commercial-off-the-shelf (COTS) and government-off-the-shelf (GOTS) tools along with some custom software. JHU/APL missions use the Integral Systems' EPOCH 2000 COTS ground system. It uses the Standard Test and Operations Language (STOL) scripting language for controlling both the spacecraft and ground system.

These tools augment a small operations team of seven people conducting both supported and lights-out operations seven days a week. The lights-out components of the TIMED MOC allow for a subset of normal operations activities in an unattended state.

3.1 Conducting Unattended Contacts

For unattended contacts, the EPOCH 2000 ground system is left up and running. A STOL script is generated for an upcoming contact by inserting the contact times into a template of activities to be performed during that contact. The STOL script is manually started by Mission Operations prior to departing for the evening. This script controls the contact through ground system configuration directives and spacecraft commands. Typical activities include loading timetag commands to the spacecraft memory and dumping the Solid State Recorders (SSR).

Automated components report planned contact activities, announce upcoming contacts and evaluate data after the contacts. For automated reporting of planned contact activities, a table showing upcoming contacts and their support level is accessible by team members via the Web. This table is updated every minute and shows in time order the upcoming contacts with the spacecraft, which ground station will be utilized for each contact, the duration of each contact, and whether instrument commanding will be permitted or not on a given contact. Staff in the instrument Payload Operations Centers (POC), the Ground Stations, and Mission Operations personnel, both on-site and off-site may monitor the voice nets for automated announcements of upcoming contacts. There is a capability to dial into this voice net from any phone number, so staff members at home may monitor the countdown to a particular contact, and obtain announcements during the contact leading up to LOS.

Upon completion of a lights out contact, automated processes in the TIMED ground system begin to ingest and evaluate data received during the contact. This consists of both real-time data and data stored on the spacecraft's solid state recorder that was retrieved during the contact. Although the ultimate goal of a platform such as TIMED is to gather science data, the engineering data that provide an indication of the spacecraft and instrument state of health are targeted for daily scrutiny by the Mission Operations team. The automated assessment tools provide listings and graphical plots of pre-defined telemetry data, hard copies of which will be waiting for Mission Operations personnel when they arrive for their shifts.

3.2 Notification of Mission Operations Personnel

Along with the components that enable automated contacts are processes that keep a silent watch over the nominal lights out operations. These processes act to notify Mission Operations personnel of potential anomalies, and provide off-site monitoring capabilities to plan for corrective action on upcoming contacts.

Expert system technology integrated into the TIMED ground system monitors the progress of the contact, monitors the health and safety of the spacecraft and initiates notification of Mission Operations personnel. NASA Goddard Space Flight Center (GSFC), in conjunction with Computer Sciences Corporation, developed an expert system environment called Generic Spacecraft Analyst Assistant (GenSAA). GenSAA is a rule-based expert system using CLIPS (C-Language Integrated Production System) developed by NASA Johnson Space Center. GenSAA has a graphical user interface tool for building rules that use telemetry point definitions. During contact with the spacecraft, GenSAA monitors the telemetry and reports anomalous conditions through a program that send text messages to pagers. GenSAA expert systems have been used for nearly a dozen spacecraft, including EUVE, CGRO, SAMPEX, WIND, SOHO, RXTE, SWAS, TRMM, ACE and NOAA-K. [3,4]

These past missions utilized GSFC's Transportable Payload Operations Control Center (TPOCC) ground system. To support the TIMED mission, GenSAA and Genie were integrated with the Integral Systems' EPOCH 2000 COTS ground system in use at JHU/APL. The integrated system allows GenSAA and Genie to receive spacecraft telemetry and ground system event messages and to send ground system directives and spacecraft commands to EPOCH 2000. [5]

The ground segment interfaces for the automated system are isolated from the telemetry format and downlink source. The system scales within a mission from a small set of rules to hundreds of rules, and from straightforward to complex missions. The knowledge base supports rules of arbitrarily complex sets of conditions and actions to be performed. The spacecraft specialists on the Mission Operations Team control the degree of complexity. The objective was to create a knowledge base that gives confidence that spacecraft health and safety is maintained. Initially a small number of conditions were monitored and a few have been added since.

NASA GSFC also developed a GenSAA application to automate spacecraft pass operations called the Generic Inferential Executor (Genie). Genie applications duplicate the routine monitoring, decision-making, and actions of flight operations personnel during a real-time contact. Genie has been used in conjunction with GenSAA in the CGRO and RXTE control centers 24 hours per day, 7 days per week. See Figure 1 for a view of Genie's control panel displaying status information, mode control and operator input controls. Although Genie can run unattended, the control panel is useful when testing the design and execution of pass scripts and can be used for manual intervention if needed. The top portion of the control panel displays the script name and status, the pass AOS and LOS times, current GMT time and the name and status of the currently executing task. The lower portion has an input line for a manual STOL directive and radio buttons to control the execution of the script.

TIMED Mission Operations uses both GenSAA and Genie. GenSAA monitors health and safety and Genie monitors the SSR dump status. Both applications send pages and/or emails to contact Mission Operations. Neither GenSAA nor Genie send spacecraft commands to TIMED although the capability exists. Instead, the systems notify the experts who then resolve any problems.

The approach to completing a working Lights Out Automated System for TIMED utilized the expertise of the spacecraft engineers and operators to define the diagnostic rules and the pass scripts. TIMED missions operations personnel identified specific critical monitoring tasks for the automated system to perform. These tasks include demotion from operational mode to either nadir mode or safe mode; a low voltage sense situation; and

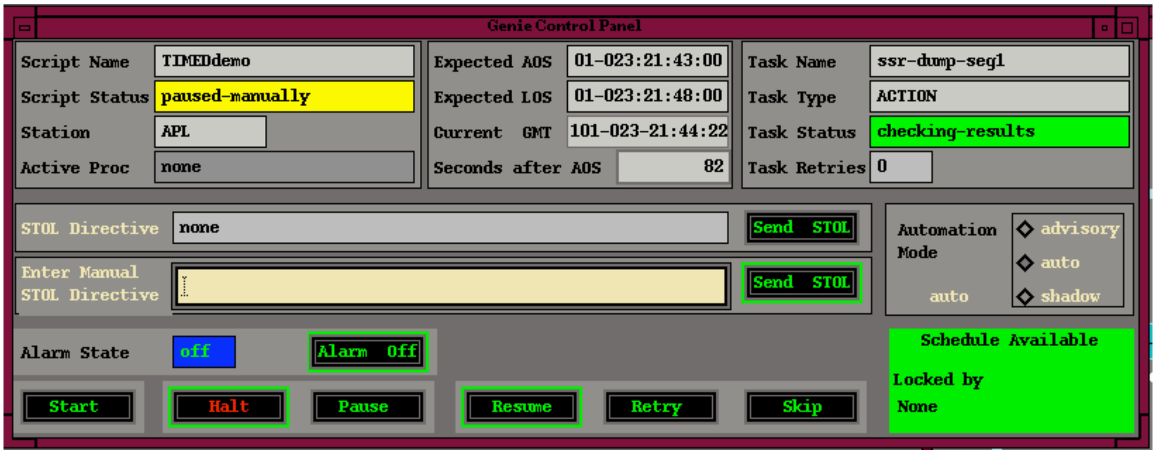

Figure 1 – Genie Control Panel

science instrument packet counts over their limit. When these conditions are detected a text message describing the situation is sent via page to the appropriate mission operations staff. The software that sends pages is a custom C++ program. It is activated through a system call initiated by the action part of the rule firing. It uses a standard unix email program to send the pages to a list of addresses kept in a file. The program is passed a parameter to determine which of several lists of personnel should be paged for the given problem. Adding an additional list is simply a matter of creating a new parameter value and a file of page or email addresses to be notified for that class of anomaly.

For the GenSAA Health and Safety Monitoring system, a total of 23 telemetry points are monitored and 26 rules are employed. Figure 2 shows the display of the GenSAA runtime interface for TIMED. The spacecraft time and mode are indicated, along with the status of the Low Voltage Sense relays and autonomy rule firing count. The downlink communication configuration is shown, as well as the instrument packet count limits and an indicator when a page has been sent to Mission Operations.

Messages are displayed on the GenSAA runtime interface as new situations are determined. The messages are generated from rules that match the predefined conditions to the appropriate action. Figure 3 shows the actual message window for TIMED covering the period from April 17, 2001 (DOY 107) through June 3, 2001 (DOY 154). During this period the spacecraft demoted to Nadir mode a total of three times. All messages are also written to a log file for further analysis.

After the Health and Safety Monitoring system had been running successfully in the TIMED Mission Operations Center (MOC) for several months, it was decided that a capability to monitor dumps from the Solid State Recorders should be added. The nature of the problem suggested the addition of Genie in the MOC. SSR dumps are seen in telemetry through a packet counter that goes from zero prior to a contact, up to a large number, and back to zero when the contact is over. Since GenSAA monitors telemetry and only acts upon changes, a failed SSR dump that leaves the packet counter at zero needs to be detected in another manner. Genie performs tasks and checks results based upon a script template that is instantiated for a specific spacecraft contact. For TIMED, Genie tasks were created that check the front end hardware configuration, look for a signal locked on the spacecraft, check for a minimal amount of data dumped from the SSR and check for the normal amount of SSR data. The paging software is integrated into Genie through a unix system call exactly the same as in GenSAA. Pages are sent when the signal does not lock on with the spacecraft or when the minimum amount of SSR data is not dumped successfully. An email notification is sent if the minimum amount of SSR data is received but less than the normal amount. An email is also sent upon successful completion of the contact. This positive confirmation that the contact was completed assures mission operations that the Genie software executed successfully.

Figure 4 shows the Genie runtime interface for the script containing these tasks. A graphical interface builds the scripts through a drop and drag technique for adding tasks and connecting the paths. Rules for the tasks and timing logic between tasks are then added. The figure shows that the first task called “Init_PASS” has completed execution and the rules are currently checking the results for the next task called “FE_Check”, which tests the configuration of the Front End equipment. The lines and arrows show the path to be taken during the pass. After a successful FE_Check, Genie will look for “SYNC_LOCK” before testing a condition for dumping the SSR on this pass. If affirmative, then the branch goes to the next task to check for a minimum amount of data dumped from the SSR before checking for a full dump and completing the script.

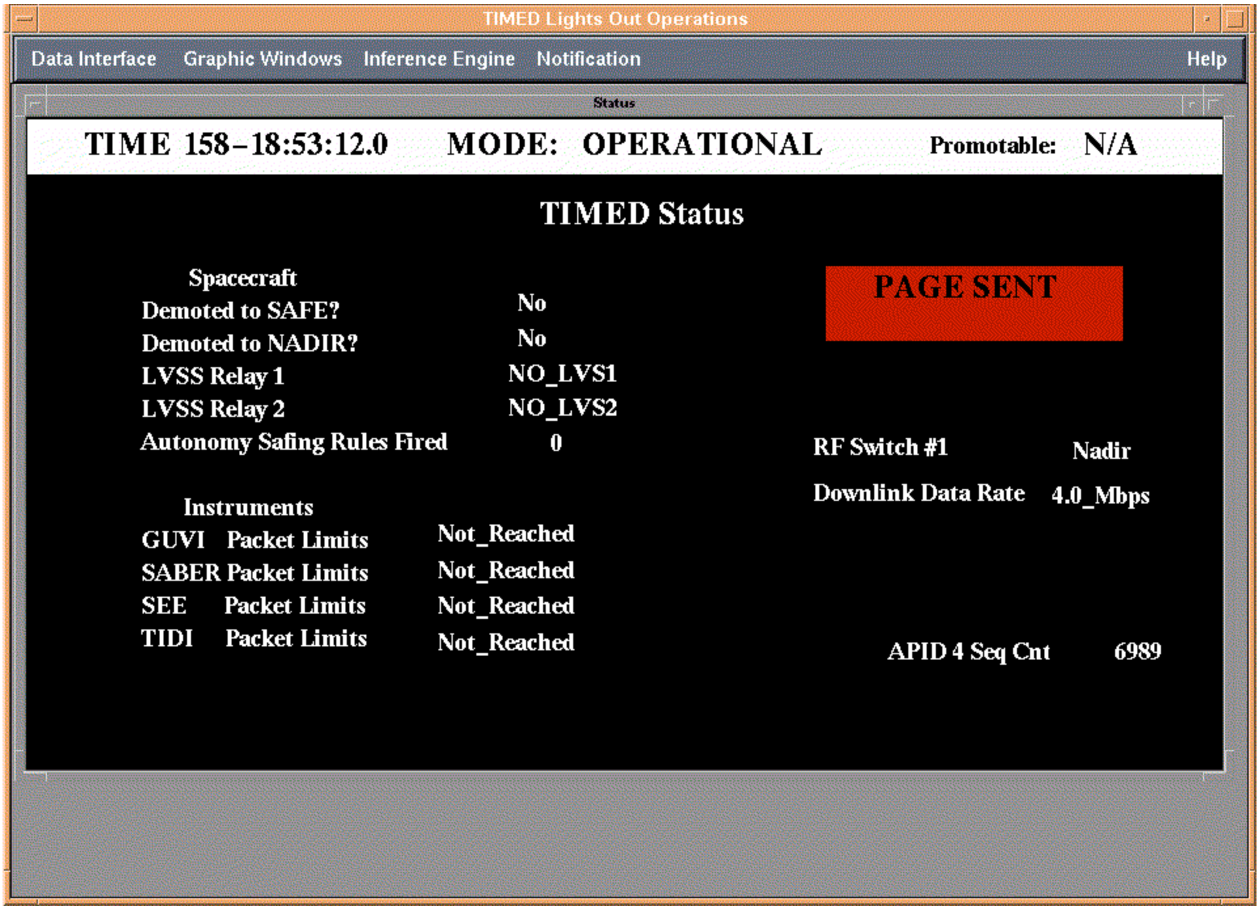

Figure 2 - GenSAA Runtime Interface for TIMED

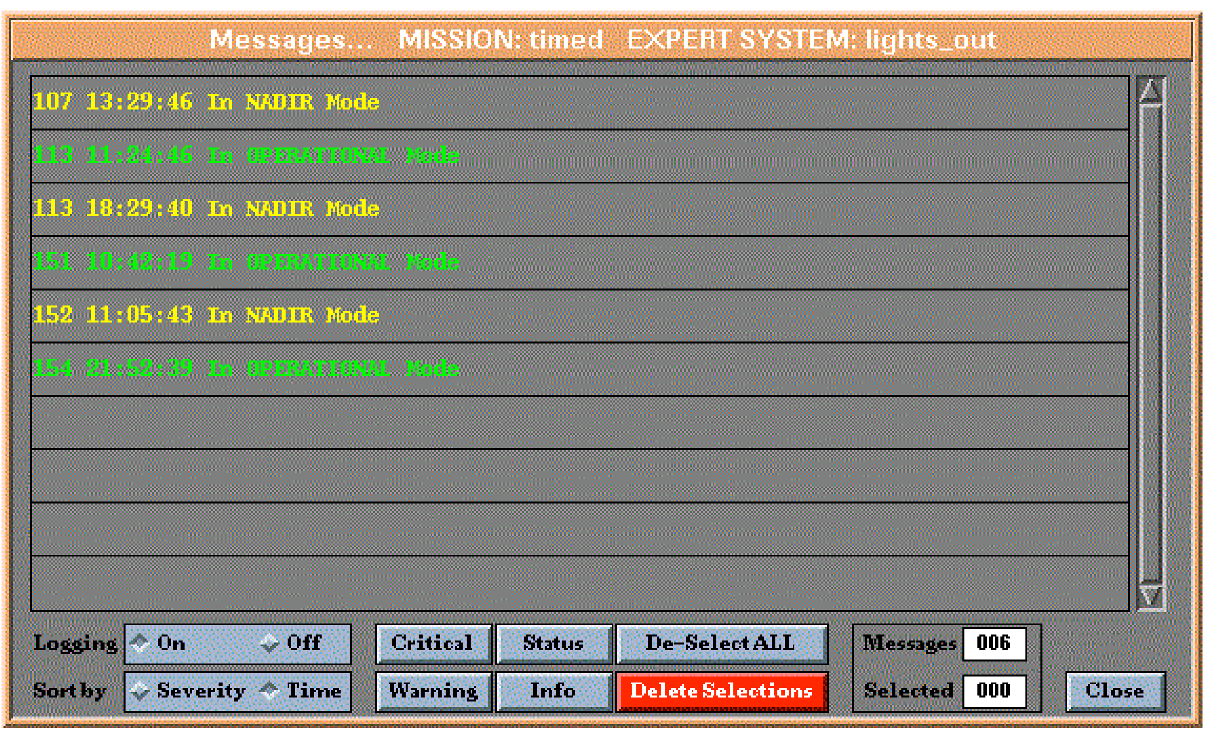

Figure 3 - GenSAA message window displaying all messages from DOY 2001-107 to 2001-154

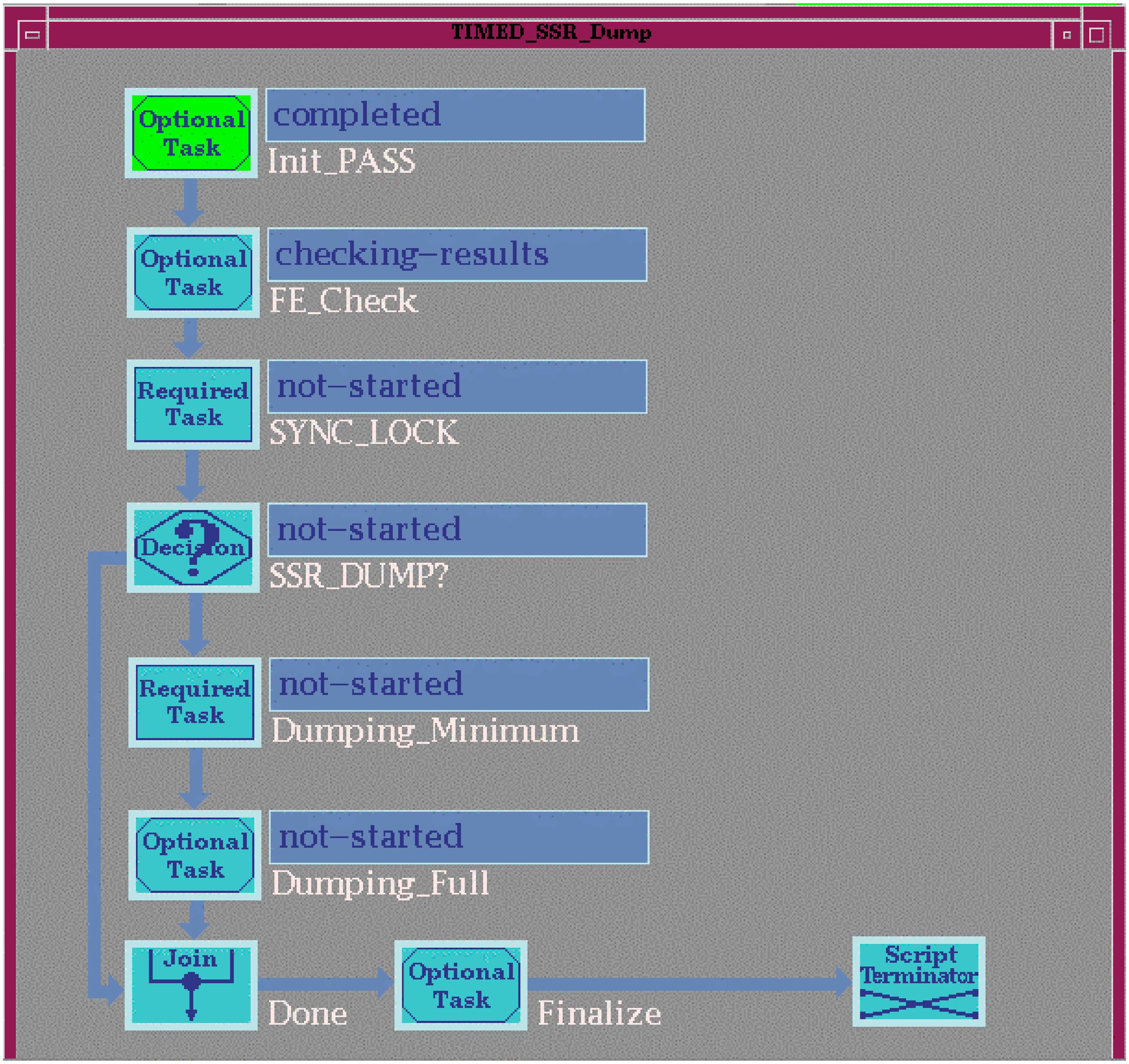

FIGURE 4 - GENIE CONTACT SCRIPT SHOWING THE TASKS FOR THE TIMED SSR DUMP MONITOR

For the Genie SSR Dump Monitoring system, a total of 35 telemetry points are monitored and 12 rules are employed.

A sample rule is shown below that checks for the minimum amount of SSR dump data and otherwise initiates a page for Mission Operations personnel. It checks the current value of a telemetry mnemonic called FE_TFI1_SIZE to see if we have received the minimum of 100Mbytes of data. If the condition part of the rule is satisfied, then the action part of the rule following the "=>" symbol is executed.

```
(defrule Dumping_Minimum-results-check
  (Mission R1_S2_PBK_CLST ?clusters)
  (Mission FE_TFI1_SIZE ?xFE_TFI1_SIZE)
  (test  (< (* clusters 119350)
                ?xFE_TFI1_SIZE))
  =>
  (retract ?xFE_TFI1_SIZE)
  (Satisfied Dumping_Minimum-results-check))
```

4. BENEFITS

The Lights Out Automated System is executed in the TIMED MOC for all contacts, whether staffed or unstafffed. TIMED's primary ground station is JHU/APL's local 60-foot antenna. The TIMED Concept of Operations calls for 1 of the 2 JHU/APL contact clusters to be supported each day. The automated system doubles JHU/APL's contact with the spacecraft by supporting the unmanned contact cluster without additional manpower costs. To support all of these contacts without an automated system, at least 13 fulltime mission operators would be required instead of the current staffing level of 7. These additional passes deliver more timely notification of anomalous situations as well as more timely science data. Anomalies are resolved sooner, resulting in better protection of the spacecraft and a quicker resumption of science activities.

To date, the Mission Operations Team and its supporting systems have helped to ensure healthy spacecraft and instrument operations while providing 100% data recovery of the recorded mission science data. Without automation and lights out capabilities, more time-consuming data reduction and analysis would be required by the operations team, and fewer contacts could be supported with the existing staff. Lights out support allows for Mission Operations to stay "ahead of the curve" by keeping up with the retrieval of stored data on the spacecraft.

Although the TIMED spacecraft has been in relatively good shape, there have been some problems either within the spacecraft or within the ground station that resulted in anomalous conditions or lost contacts detected by the expert systems. The first year of operations with TIMED resulted in a total of 29 pages generated. Many of these occurred during normal staffed contacts but many also occurred during unstafffed contacts and enabled mission operations personnel to react to the problem without having to wait until the next regular day shift. Table 1 lists the type of conditions detected. All of the root causes to these anomalies have been resolved.

Type of Anomaly	# of occurrences
Demoted to Safe Mode	5
Demoted to Nadir Mode	10
TIDI packet count over limit	2
SABER packet count over limit	1
Less than expected SSR data	6
Front End never reached Sync_Lock	5

Table 1. Types of anomalies detected on TIMED by the Lights Out System

Combining these proven off-the-shelf tools resulted in a general purpose Lights Out Automated System at a nominal cost while leveraging the expertise of pioneers in the field. The value relates directly to cost reduction in our EPOCH-based missions. Replication for other EPOCH missions is straightforward. Reducing costs in this fashion will allow future missions to remain feasible.

The system supports new missions with no software coding and no modification to the ground control center.

Customization for a new mission will be performed using graphical interface tools. One tool builds the diagnostic knowledge base for anomaly detection and another tool creates the pass scripts using the EPOCH 2000 Standard Test and Operations Language (STOL) scripting language. The spacecraft engineers and operators use the tools directly. Modifications to the pass scripts or to add new diagnostic rules are likewise made without software changes.

5. FUTURE WORK

TIMED flies four science instruments each of which have their own, decentralized Payload Operations Center (POC). We have offered to add monitoring for critical instrument telemetry and to page POC personnel when problems arise with their instrument. At least one POC has responded requesting the capability.

Since our future JHU/APL missions will use the EPOCH 2000 ground system, they plan to utilize the lights out capabilities described here. The STEREO mission comprised of two spacecraft includes automated contacts during unstafffed shifts and will use GenSAA and Genie in their control center starting with the Integration and Testing (I&T) phase.

In addition, we are investigating the design and development of more generic core components that reduce some of the current dependencies that GenSAA and Genie have. Since these tools were originally developed in the early 90's they contain some currently unsupported tools and libraries such as graphical interfaces and HP operating system dependencies. Our goal is to develop a platform independent version based upon the Java version of CLIPS with a Java data server for easier integration with different ground systems and custom tools.

6. CONCLUSION

In summary, we have integrated automated capabilities within our ground system to enable lights out contacts that include conducting normal operations for uplinking commands, downlinking housekeeping and science data, monitoring for health and safety and notifying staff of anomalous situations. By reducing the cost of developing and operating missions, without increasing risk or decreasing science, we are better able to support future missions.

REFERENCES

[1] P. M. Hughes, Initiatives for Automating Satellite Operations at the NASA-Goddard Space Flight Center, *Proceedings of the 1st International Symposium on Reducing the Cost of Spacecraft Ground Systems and Operations,* Oxfordshire, UK, September 1995

[2] S. M. Krimigis, T. B. Coughlin and G. E. Cameron, Johns Hopkins APL Paradigm In Smallsat Management, *Acta Astronautica*, Vol 46, Nos. 2-6. PP 187-197, 2000

[3] J. Hartley, E. Luczak, and D. Stump, Spacecraft Control Center Automation Using the Generic Inferential Executor (Genie), *Proceedings of the Fourth International Symposium on Space Mission Operations and Ground Data Systems (SpaceOps96),* Greenbelt, MD, September, 1996

[4] C. Penafiel, D. B. LaVallee, and M. Heidenrich, Development of an Automated Control Center for the EUVE Mission, *Proceedings. of the Fourth International Symposium on Space Mission Operations and Ground Data Systems (SpaceOps96),* Greenbelt, MD, September, 1996

[5] D. B. LaVallee, COTS Integration For Lights Out Support, *Proceedings of the Fourth International Symposium on Reducing the Cost of Spacecraft Ground Systems and Operation's,* Laurel, MD, April 2001.

David LaVallee *has developed and led development of software at Johns Hopkins University's Applied Physics Laboratory, Lockheed Martin, Loral, Ford Aerospace and Vitro Labs. He led the development of the ground support software for NEAR and has extensive experience in ground systems, including expert system integration and development of a generic command system. He also developed software for the Air Force and Navy cruise missile programs. He has a BS from the University of Pennsylvania and an MS in computer science from The Johns Hopkins University.*

William Knopf *is the Mission Operations Manager for the TIMED spacecraft. He has extensive experience in ground system software development and operations analysis for Navy and NASA programs. He has worked in both software and operations roles for the Delta-181, MSX, NEAR and TIMED programs, and provided tracking system analysis for the Navy's Flight Support System. He has a BS in Physics from Villanova, an MS in Physics from Drexel University and an MS in Computer Science from The Johns Hopkins University.*

ACKNOWLEDGEMENT

The authors would like to thank the TIMED Program Office at NASA Goddard Space Center for their support of this mission.